TECHNICAL MEMORANDUMS

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No. 775

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TOTAL-HEAD METER WITH SMALL SENSITIVITY TO YAW

By G. Kiel

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# NOTICE

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TOTAL-HEAD METER WITH SMALL SENSITIVITY TO YAW*

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SUMMARY

The conventional method of calibrating the flight dynamic pressure in quadrangular flights is not altogether satisfactory in many cases, and at times even absolutely inapplicable (for instance, for dynamic pressure calibration in the range of maximum lift, in climbing or power-off flight). A more accurate and generally more practical method is to so record the dynamic pressure that the total head is recorded at the wing and the static pressure is obtained from a pitot-survey apparatus trailing in undisturbed air flows beneath the airplane. This, however, calls for a total-head meter of small sensitivity to yaw, such as we developed.

This apparatus is essentially a venturi, housing a pitot tube for obtaining the total head. In yaw the flow within the nozzle is deflected, depending upon the degree of yaw, to a greater or lesser extent into the axial direction of the nozzle. After experimenting with several nozzle forms as to their suitability, the best design was finally adopted. One feature common to all investigated forms was, that the point least affected by yaw was at a distance of 0.5 diameter downstream from the entrance section. When, with the chosen nozzle form, the total head is 0.5 entrance section diameter downstream, the instrument supplies the genuine total head at low Reynolds Numbers up to $40^\circ$ yaw, at high Reynolds Numbers up to $43^\circ$ yaw.

The instrument meets all practical requirements. It has proved satisfactory in the wind tunnel as well as in free flight. It has the dual advantage of being very simple and minus any mechanically moving parts.

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*"Gesamtdruckgerät mit grosser Unempfindlichkeit gegen Schräganströmung." Luftfahrtforschung, May 16, 1935, pp. 75-79.

## INTRODUCTION

The conventional method of calibrating the dynamic pressure in flight measurements is by means of a fixed instrument and quadrangular flight. These calibrations, however, are not always satisfactory. As the coefficient of advance of the propeller changes, the lift and velocity distribution also assume different form. To use calibration curves obtained from level quadrangular flights (thrust = drag) for evaluating measurements from climbing or idling flight, may introduce considerable errors. These sources of error can, however, be avoided when the permanently installed dynamic pressure apparatus is also adequately calibrated in climbing and idling flight. Calibration is afforded in all cases (level flight, climb, or throttled flight) when the dynamic pressure is measured in such a way that the total head is taken from a total-head meter located on the wing, while the static pressure is obtained with a static survey apparatus trailing in the undisturbed air below the airplane.

The premise for the satisfactory measurement of the dynamic pressure is the exact recording of the total head as well as of the static pressure. However, inasmuch as the location for mounting the total-head meter may be exposed to considerable changes in air-flow direction, the total-head meter must be such as to assure an accurate record even in considerable yaw.

## PHYSICAL PRINCIPLES

A small sensitivity of total-head readings in yaw may be achieved in various ways. For example, a freely rotating instrument may be used; but such devices are frequently unhandy because of their bulk, aside from the fact that the moving parts constitute a source of interference.

In a rotationally symmetrical cylinder of suitable length, in yaw, the air stream within the cylinder is deflected to a greater or lesser extent, according to the degree of yaw, into the axial direction of the cylinder. The conditions are illustrated in figure 1 for a simple cylinder, and in figure 2, for a venturi-shaped cylinder. Both are of glass so as to show the flow within. The liquid was water with minute silver crystals (reference 1).

By using a small slotted diaphragm, a plane of light was
placed through the moving fluid and the inside of the
cylinder, so that a small fluid layer became visible.  In
this manner it was possible to observe and photograph the
streamlines in the plane of intersection at various de-
grees of yaw.  The angle $\sigma$ between undisturbed stream di-
rection and axis of symmetry of the cylinder is also
shown on the photographs.  The rate of flow of the water
was 0.15 to 0.2 m/s (0.49 to 0.656 ft./sec.).  These flow
pictures reveal very clearly how the flow is deflected
into axial direction up to comparatively great yaw.  The
nozzle-shaped cylinder in figure 2 is particularly impres-
sive.  Here the deflection in axial direction persists up
to quite considerable yaw.

Now according to Bernoulli's theorem, the total head
in the nonturbulent flow past a streamline is constant.
If the total head is measured by pitot tube in the cylin-
der, particularly the nozzle, within range of the undis-
turbed air stream and at a point where this flow is at
least approximately in axial direction, then the total
head must be the true head even up to great yaw.*

TOTAL-HEAD ERRORS ALONG THE AXIS OF

SEVERAL ROTATIONALLY SYMMETRICAL NOZZLES IN YAW

The problem was now resolved to:

1.  Finding a suitable form of the rotationally sym-
    metrical cylinder deflecting the flow, and

2.  Establishing the best point within the cylinder
    for measuring the total head.

Whence the investigation of divers nozzle forms as to
their suitability in the small wind tunnel of the DVL.
(See fig. 3.)  The test arrangement is sketched in figure

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*This method was previously employed by Betz but, unfortu-
nately, literature fails to give any further details.  See
H. Peters' "Pressure Recording" in Handbuch der Experimen-
talphysik, vol. IV: Hydro- und Aerodynamik I, p. 499.
Published by L. Schiller.  Akademische Verlagsgesellschaft
m.b.H., Leipzig, 1931.

4.   The total-head difference $p_g - p_{g_0}$   along the axis
was measured at different yaw positions $\sigma$ of the nozzles
with respect to the flow direction.  Hereby $p_g$ = indicat-
ed total head; $p_{g_0}$ = actual total head of flow.  The meas-
urements were made with constant $\sigma$ while varying the dis-
tance  $a$  of the pressure measurement from the entrance
section.  The actual total head was established by accu-
rate calibration.  The experiments were made at  $q = 100$
$kg/m^2$ (20.48 lb./sq.ft.) dynamic pressure, while the com-
pleted instrument was tested simply at different dynamic
pressures with a view to any eventual scale effects.  The
pressure was measured with a micromanometer having an in-
dicating accuracy to within 1/10 to 1/20 $kg/m^2$ (0.021 to
0.041 lb./sq.ft.) (reference 2).  On the basis of 1/10 $kg/$
$m^2$ (0.021 lb./sq.ft.) micromanometer accuracy together
with assuming that the pitot tube registers the total head
only within an accuracy of 0.001, the instrumental accu-
racy of the experiments made with 100 $kg/m^2$ (20.48 lb./
sq.ft.) dynamic pressure, is about 0.002.

The test results are reproduced in figures 5 to 7.
The total-head error for the individual forms at differ-
ent yaw $\sigma$ is plotted in percent of the dynamic pressure
$\left(100 \dfrac{p_g - p_{g_0}}{q}\right)$ versus distance  $a$  from the entrance sec-
tion; this distance  $a$  being expressed in diameters of
entrance section $D$, that is, the ratio  $a/D$.  The experi-
mental results reveal that in all explored cylinders the
curves $100 \dfrac{p_g - p_{g_0}}{q} = f\left(\dfrac{a}{D}\right)$ at any yawed position ap-
proach zero value more or less at about the same distance
from the entrance section; that is, $\dfrac{a}{D} \approx 0.5$.  The best
form is that of nozzle 2, with its particularly favorable
flatness of the total-head curves in the vicinity of ap-
proaching zero value.  It indicates that a small shifting
of the total-head measurement in the vicinity of  $\dfrac{a}{D} = 0.5$
has practically no effect on the total-head reading.  Noz-
zle 3 is the shortened nozzle 2 and not as favorable as 2,
according to the measurements.

Figure 8 shows the total-head error at $\dfrac{a}{D} = 0.5$  in
percent of dynamic pressure versus yaw

$$\left(100 \ \frac{p_g - p_{g_0}}{q} = f(\sigma) \ \text{at} \ \frac{a}{D} = 0.5\right).$$

The comparison here is even more striking than in figures 5 to 7. Nozzle 2 is distinctly superior; at $\frac{a}{D} = 0.5$ the total head remains without error up to $45^\circ$ yaw.

## FINAL FORM OF TOTAL-HEAD METER, ITS TEST IN

## THE WIND TUNNEL AND IN FREE FLIGHT

Since in order to be practical in flight the instrument must be convenient and of small bulk, nozzle 2 was again investigated with smaller dimensions. The measurements made in the same manner as before showed the same result as the larger nozzle 2.

The final total-head meter is shown in figures 9, 10, and 11. The principal dimensions are seen from figure 9, expressed in multiples of nozzle diameter.

The final apparatus was then tested in the described manner in the wind tunnel. The total-head error is plotted in percent of $100 \ \dfrac{p_g - p_{g_0}}{q}$ versus $\sigma$ at different Reynolds Numbers in figure 12. The dependence on the Reynolds Number is quite small. At low $R$ the sensitivity to yaw is slightly greater. The deviation of the error curve with the finished instrument occurs somewhat earlier than with the experimental nozzles, according to figure 12. There also is a small point of discontinuity, caused probably by a disturbance of the smooth flow through the pitot-tube supports. The instrument meets any requirement encountered in practice. It can in all cases be used up to $40^\circ$ yaw and at high speeds up to $43^\circ$ yaw. The experiments further revealed that by preserving the same dimensional figures the instrument can be manufactured in any desired size and be used in any practical way without calibration of each individual instrument.

To prove its practical usefulness in exact flight measurements, the total-head meter was subjected to flight

tests, consisting of quadrangular flights, during which
the dynamic pressure was measured by total-head meter and
a static-survey apparatus trailing below the airplane.
To make these comparative measurements truly representa-
tive, these flights were made only in very calm weather
(fig. 13).  The accord of both measuring methods is very
satisfactory, and proves that the instrument is equally
practicable for wind-tunnel and free-flight tests.


Translation by J. Vanier,
National Advisory Committee
for Aeronautics.



REFERENCES

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        vol. 14, no. 12, 1933, pp. 566-567.

2.  Betz, A.:  Ein neues Mikromanometer.  Ergeb. Aero.
        Vers. no. IV, 1932, pp. 12-13.

$\sigma = 0^\circ$     $\sigma = 27^\circ$

$\sigma = 20^\circ$     $\sigma = 43^\circ$
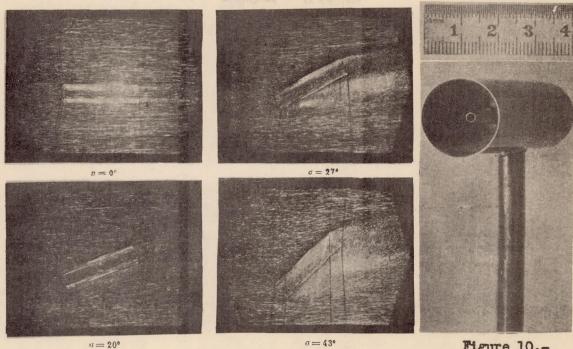
Figure 1.- Flow pictures of a cylinder in yaw $\sigma$.



Figure 10.- Completed total head meter.



$\sigma = 0^\circ$     $\sigma = 25^\circ$

$\sigma = 17^\circ$     $\sigma = 39^\circ$
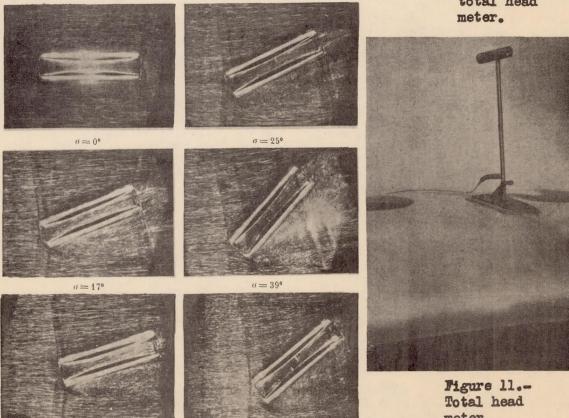
$\sigma = 21^\circ$     $\sigma = 47^\circ$

Figure 2.- Flow pictures of a venturi tube in yaw $\sigma$.



Figure 11.- Total head meter mounted on wing.
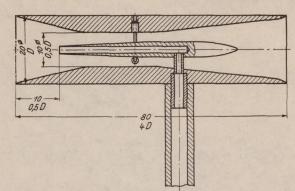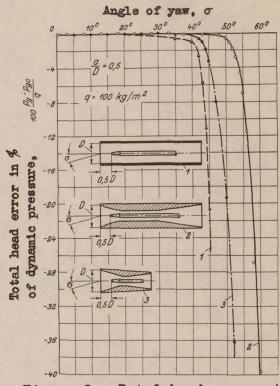
Figure 9.- Final total head meter.

Figure 8.- Total head error at a/D = 0.5 against yaw σ for different nozzle forms.

Total head meter

Figure 13.-
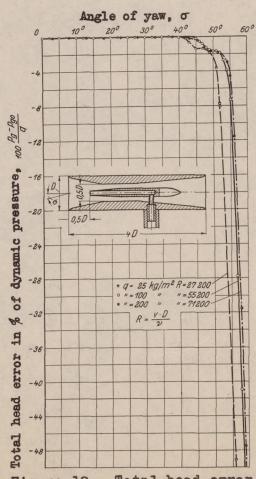
Figure 12.- Total head error of final instrument against yaw.

Figure 3.- Experimental nozzles.



Figure 5.- Total head error against a in yaw σ.



Figure 7.- Total head error against a in yaw σ.



Figure 4.- Sketch of experimental arrangement.



Figure 6.- Total head error against a in yaw σ.